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FORCE TESTS OF THE SATURN V LOR AND
SATURN 1B/AS-206 CONFIGURATIONS
AT MACH NUMBERS 1.5 THROUGH 8

Leroy M. Jenke

ARO, Inc.

February 1967

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

FORCE TESTS OF THE SATURN V LOR AND
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ARO, Inc.

FOREWORD

The work reported herein was done for the Marshall Space Flight Center (MSFC), at the request of the National Aeronautics and Space Administration (NASA) under System 921E, Project 9064.

The results of tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted intermittently within the period from July 22 to October 11, 1966 under ARO Project No. VT1693. The manuscript was submitted for publication on December 7, 1966.

This technical report has been reviewed and is approved.

James N. McCready
Major, USAF
AF Representative, VKF
Directorate of Test

Leonard T. Glaser
Colonel, USAF
Director of Test

ABSTRACT

Static force tests were conducted in the 40-in. supersonic and 12-in. hypersonic tunnels of the von Kármán Gas Dynamics Facility on models of the Saturn V LOR and Saturn 1B/AS-206. Data were obtained at Mach numbers 1.5 through 8 at angles of attack from -4 to 13 deg. The Reynolds number, based on the booster diameter, ranged from 0.24×10^6 to 1.67×10^6. The results presented show the effects of Mach number and model attitude on the static longitudinal stability and axial-force characteristics.

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NOMENCLATURE

A	Reference area (booster cross-sectional area), in.^{2} (see Fig. 1)
A_b	Base area, in.^{2} (see Fig. 1)
C_A	Forebody axial-force coefficient, $C_{A_T} - C_{A_b}$
C_{A_b}	Base axial-force coefficient, $-C_{p_b}(A_b/A)$
C_{A_T}	Total axial-force coefficient, $\dfrac{\text{total axial force}}{q_\infty A}$
C_m	Pitching-moment coefficient, pitching moment/$q_\infty A d$
C_{m_α}	Initial slope of the pitching-moment curve, deg^{-1}
C_N	Normal-force coefficient, normal force/$q_\infty A$
C_{N_α}	Initial slope of the normal-force curve, deg^{-1}
C_{p_b}	Base pressure coefficient, $(p_b - p_\infty)/q_\infty$
d	Booster diameter, in. (see Fig. 1)
M_∞	Free-stream Mach number
p_b	Model base pressure, psia
p_0	Tunnel stilling chamber pressure, psia
p_∞	Free-stream static pressure, psia
q_∞	Free-stream dynamic pressure, psia

Re_d Reynolds number based on booster diameter

T_O Tunnel stilling chamber temperature, °F

x_{cp} Center-of-pressure location forward of the moment reference, $C_{m_\alpha}/C_{N_\alpha}$, calibers

α Angle of attack, deg

SECTION I
INTRODUCTION

Static force tests were conducted in the 40-in. supersonic and 12-in. hypersonic tunnels (Gas Dynamic Wind Tunnels, Supersonic (A) and Hypersonic (E)) of the von Kármán Gas Dynamics Facility (VKF), AEDC, AFSC, to obtain the longitudinal static stability and axial-force characteristics of the Saturn 1B/AS-206 and the current Saturn V Lunar Orbital Rendezvous (LOR) launch configuration.

Data were obtained at Mach numbers from 1.5 to 8 for an angle-of-attack range of -4 to 13 deg and at Reynolds numbers based on the booster diameter, which ranged from 0.24×10^6 to 1.67×10^6.

SECTION II
APPARATUS

2.1 WIND TUNNELS

Tunnel A is a continuous, closed-circuit, variable density wind tunnel with an automatically driven flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel operates at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 300°F ($M_\infty = 6$). Minimum operating pressures are about one-tenth of the maximum at each Mach number.

Tunnel E is an intermittent, variable density wind tunnel with a nozzle formed by contoured throat blocks and manually adjusted flexible plates. The tunnel has a 12- by 12-in. test section and operates at Mach numbers from 5 to 8 at maximum stagnation pressures from 400 to 1600 psia, respectively, and at stagnation temperatures up to about 900°F. Minimum operating pressures are about one-fourth of the maximum.

A description of the tunnels and airflow calibration information may be found in the <u>Test Facilities Handbook</u>*.

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*<u>Test Facilities Handbook</u> (Sixth Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, November 1966.

2.2 MODELS

The models were supplied by MSFC. Two models of the Saturn V LOR were provided, a 0.9-percent scale model which was tested at Mach numbers from 1.5 to 6 in Tunnel A and a 0.3366-percent scale model which was tested in Tunnel E at Mach numbers from 5 to 8. The Saturn 1B/AS-206 model was 0.55-percent scale. The models were provided with alternate aft body sections so that data could be obtained on the Saturn V LOR without fins and engine shrouds and on the Saturn 1B/AS-206 without fins. Model details are given in Fig. 1 (Appendix), and photographs of the models installed in the tunnels are given in Fig. 2.

On all tests of the Saturn V LOR 0.9-percent scale model, a boundary-layer trip composed of a 0.1-in.-wide band of No. 40 carborundum grit was located on the escape tower approximately midway between the tip and shoulder of the conical nose. The 0.3366-percent model was tested at Mach 5 with and without a boundary trip composed of a single row of steel balls (0.010-in.-diam) located at approximately the same location on the escape tower as the trip on the 0.9-percent scale model. No effect of the trip was observed; therefore, the data with trips are not presented.

2.3 INSTRUMENTATION

Model force measurements were made with six-component, moment-type, strain-gage balances supplied and calibrated by VKF. Before the tests, static loadings in each plane and combined static loadings were applied to each balance which simulated the range of model loadings anticipated for the tests. The ranges of uncertainties listed below correspond to the differences between the applied loads and the values calculated by the balance equations used in the final data reduction. The minimum uncertainties are for loads up to about 10 percent of the maximum applied and are for loadings on the particular component only (no combined loading interaction effects). The maximum uncertainties are for combined loadings. Since the normal force, pitching moment, and axial force were of primary interest, only the uncertainties for these components are presented.

Saturn V (0.9-percent Scale) - Tunnel A

Balance Component	Design Load	Range of Static Loading	Range of Uncertainties
Normal force, lb	150	±3 to ±60	±0.02 to ±0.14
Pitching moment, in.-lb	760	±8 to ±210	±0.08 to ±0.30
Axial force, lb	75	±4 to ±60	±0.15 to ±0.33

Saturn V (0.3366-percent Scale) and Saturn 1B (0.55-percent Scale) - Tunnel E

Balance Component	Design Load	Range of Static Loading	Range of Uncertainties
Normal force, lb	25	±2 to ±24	±0.03 to ±0.07
Pitching moment, in.-lb	80	±8 to ±75	±0.10 to ±0.25
Axial force, lb	8	±1 to ±6	±0.01 to ±0.07

Saturn 1B (0.55-percent Scale) - Tunnel A

Balance Component	Design Load	Range of Static Loading	Range of Uncertainties
Normal force, lb	30	±2 to ±20	±0.02 to ±0.06
Pitching moment, in.-lb	66	±3 to ±34	±0.03 to ±0.15
Axial force, lb	30	±1 to ±20	±0.01 to ±0.06

The balance used for the Tunnel E tests was cooled by a water jacket which extended over the entire length of the balance. The forward end of the Tunnel E sting was also water cooled. Balance temperatures were measured by copper-constantan thermocouples and monitored during all tests.

In Tunnel A, the base pressures were measured with transducers of 15-, 5-, and 1-psid capacity referenced to a near vacuum and are considered accurate to within 0.25 percent of the transducer capacity. In Tunnel E, the base pressures were measured with 5-psid transducers referenced to an independently variable pressure system and are considered accurate to within ±0.005 psi.

A summary of the test conditions and configurations tested is given in Table I.

TABLE I
TEST SUMMARY

Nominal M_∞	Calibrated M_∞	Tunnel	P_0, psia	T_0, °F	$Re/ft \times 10^{-6}$	$Re_d \times 10^{-6}$	Saturn V (0.9-percent Scale)		Saturn V (0.3366-percent Scale)		Saturn V (0.55-percent Scale)	
							With Fins	Without Fins	With Fins	Without Fins	With Fins	Without Fins
1.5	1 53	A	13.5	100	3.84	1.14	X	X				
1.5	1.52	A	21.5	100	6.12	0.72					X	X
1.75	1.76	A	23.8	100	6.36	0.75					X	X
2.0	2.00	A	16.0	100	3.84	1.14	X	X				
2.0	2.00	A	28.2	100	6.84	0.81					X	X
2.5	2.49	A	18.7	100	3.60	1.07	X	X				
2.5	2.50	A	29.6	100	5.65	0.56					X	X
3.0	3.00	A	33.1	100	4.80	1.43	X	X				
3.0	2.99	A	29.9	100	4.44	0.52						X
3.5	3.50	A	45.1	100	5.15	1.53	X					
3.5	3.50	A	40.3	100	4.55	0.54						X
4.0	4.02	A	60.3	100	5.15	1.53	X					
5.0	5.03	E	310	220	12.00	1.41					X	X
5.0	5.04	E	328	230	15.00	1.67			X	X		
5.0	5.05	A	115	165	5.15	1.53	X					
6.0	5.91	A	81	165	2.40	0.71	X	X				
6.0	5.99	A	174	165	5.15	0.61					X	X
6.0	6.04	E	270	395	4.80	0.57					X	X
6.0	6.08	E	528	420	8.76	0.97			X	X		
7.0	7.08	E	350	590	3.12	0.37					X	X
7.0	7.12	E	570	625	4.68	0.52			X	X		
8.0	7.77	E	410	825	2.04	0.24					X	X
8.0	7.81	E	575	850	2.76	0.31			X	X		

Note: For the Saturn V model without fins, the shrouds are also removed.
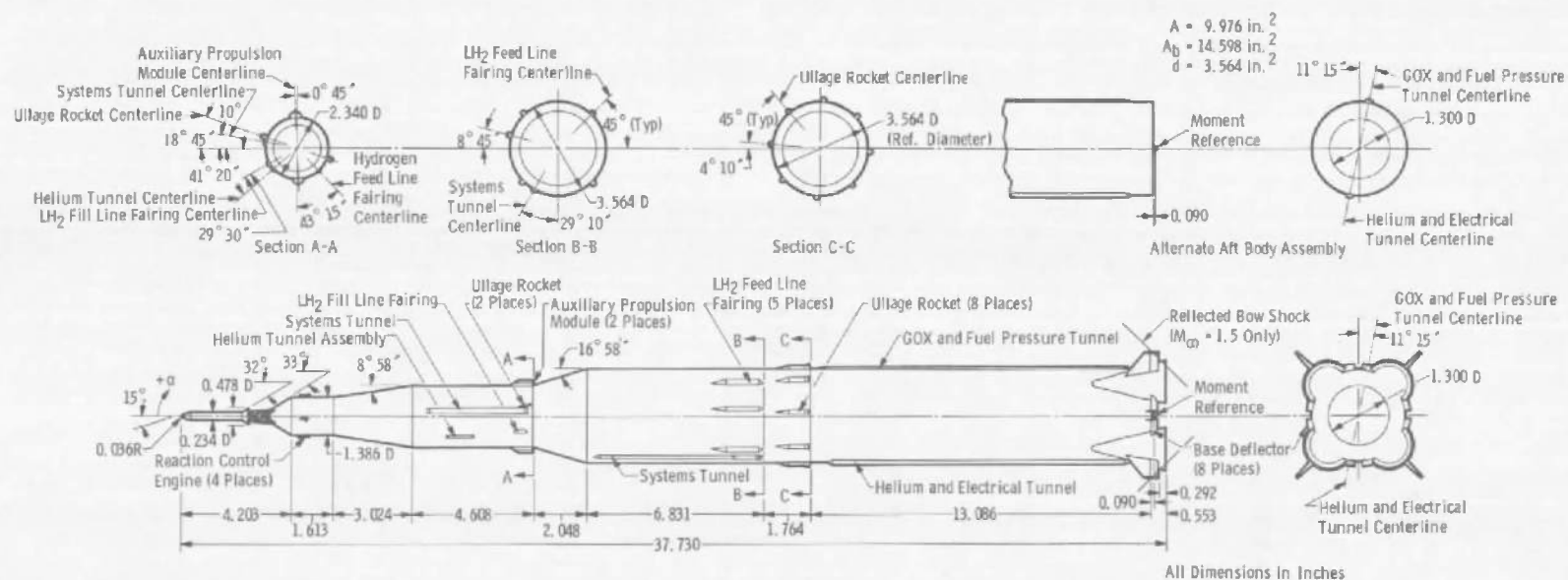
SECTION III
RESULTS AND DISCUSSION

Static longitudinal stability and axial-force characteristics for the Saturn V LOR are presented in Figs. 3 and 4. Plots of C_N, C_m, and C_A versus angle of attack are given in Fig. 3, and summary plots showing the variations with Mach number of C_{N_α}, C_{m_α}, x_{cp}, and $C_{A_{\alpha = 0}}$ are given in Fig. 4. Similar results for the Saturn 1B/AS-206 are presented in Figs. 5 and 6.

These results show the decrease in normal force and axial force and the forward shift in the center-of-pressure location obtained when the shrouds and fins are removed from the Saturn V LOR and the fins from the Saturn 1B/AS-206. Pitching moment was essentially unaffected by the configuration change. The decrease in axial force with fins removed was reasonably constant with angle of attack; consequently, these data were not included in Figs. 3c and 5c. It should be noted that for the 0.9-percent scale model at Mach 1.5, the data were obtained with the reflected bow shock impinging on the fins to the extent noted in Fig. 1a.
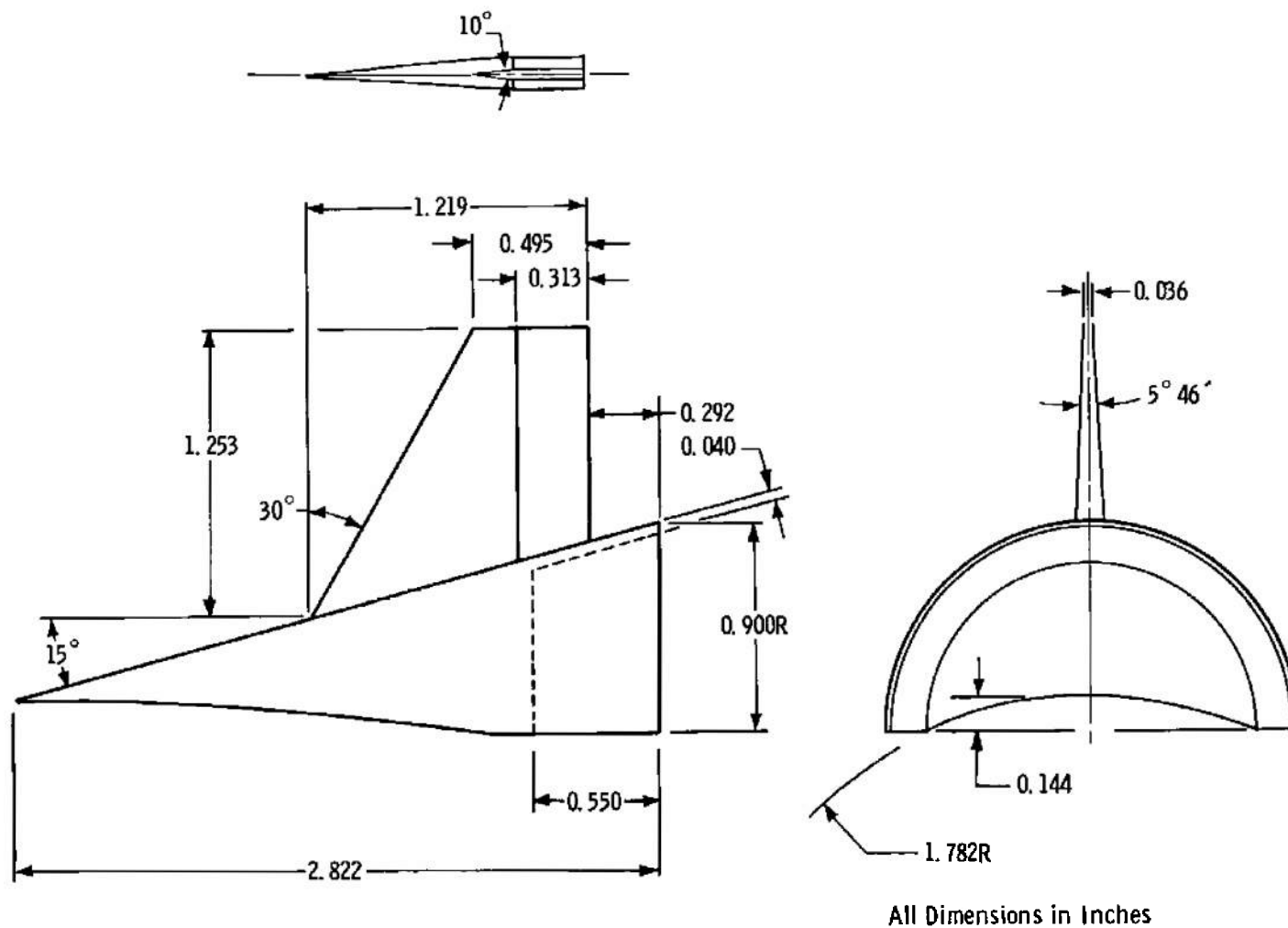
The summary plots of Figs. 4 and 6 show that the center-of-pressure variations over the complete Mach number range (M_∞ = 1.5 to 8) were within 1.5 calibers (booster diameters) for the Saturn V LOR and about 1.6 calibers for the Saturn 1B/AS-206. These data also show that good agreement was obtained between the results from both tunnels at the Mach numbers (M_∞ = 5 and 6) where repeat data were taken. This is noteworthy in the case of the Saturn V LOR when the difference in the model scales for both tunnels is considered.

It may be noted that the axial-force results for the Saturn V LOR with fins and shrouds removed at the higher Mach numbers (Tunnel E tests) are not included in Fig. 4. It is believed that these data did not match the Tunnel A results because of a small increment in axial force which was produced by the balance cooling water lines (see Fig. 2b), which were not as well shielded from the airstream as for the other model configurations. Figure 4 also shows a noticeable decrease in $C_{A_{\alpha = 0}}$ for the Saturn V LOR vehicle at M_∞ = 8. This can also be seen in the axial-force results of Fig. 3c, which show a dip in the C_A curve through α = 0 which is typical of the results obtained when flow separation is present on a body at small angles of attack.
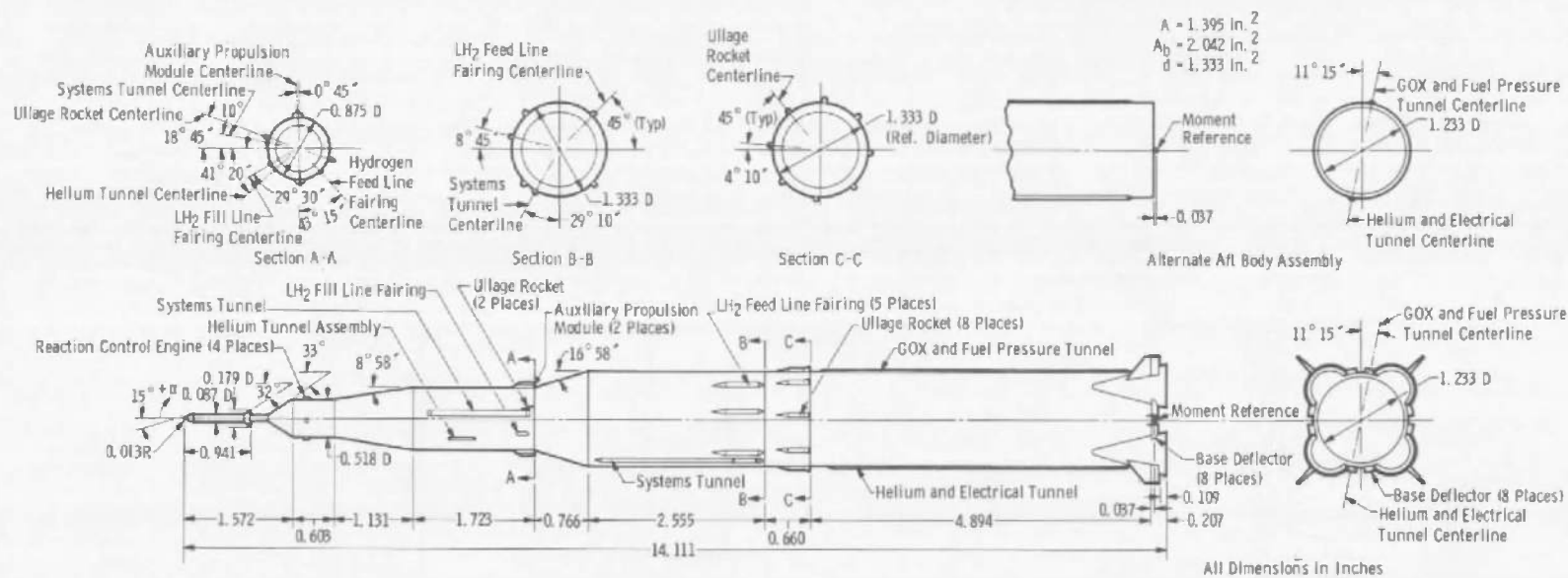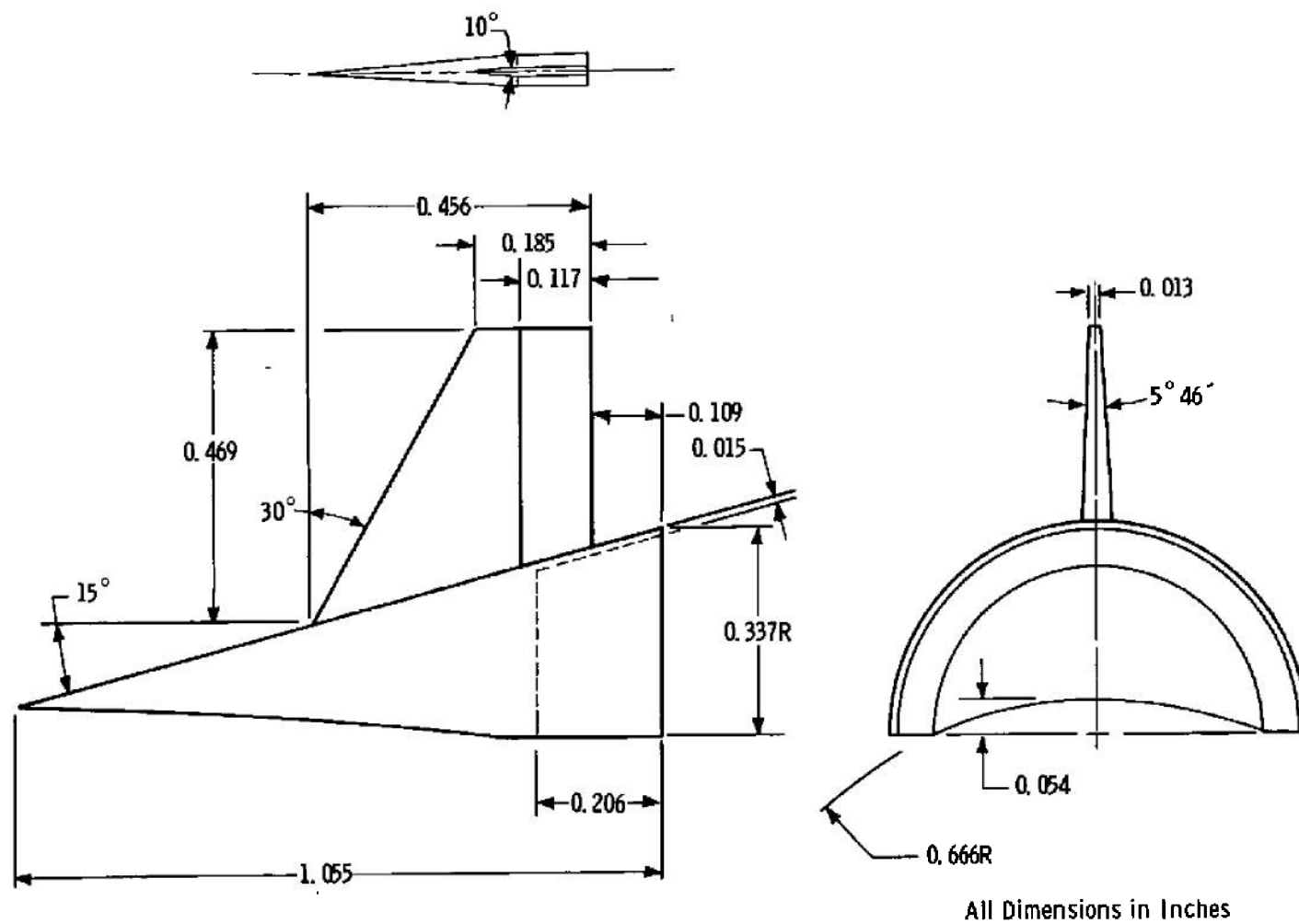
APPENDIX
ILLUSTRATIONS

a. Saturn V LOR (0.9-percent Scale Model)
Fig. 1 Model Sketches

All Dimensions in Inches

b. Saturn V LOR Fin and Shroud Details (0.9-percent Scale Model)
Fig. 1 Continued

Section A-A

Auxiliary Propulsion
Module Centerline
Systems Tunnel Centerline
Ullage Rocket Centerline
0° 45'
10°
0.875 D
18° 45'
Hydrogen
Feed Line
41° 20'
Fairing
Helium Tunnel Centerline
29° 30'
Centerline
LH₂ Fill Line
45° 15'
Fairing Centerline
Section A-A

Section B-B

LH₂ Feed Line
Fairing Centerline
45° (Typ)
8° 45'
Systems
Tunnel
1.333 D
Centerline
29° 10'
Section B-B

Section C-C

Ullage
Rocket
Centerline
45° (Typ)
1.333 D
(Ref. Diameter)
4° 10'
Section C-C

Alternate Aft Body Assembly

$A = 1.395$ in.^{2}
$A_b = 2.042$ in.^{2}
$d = 1.333$ in.^{2}
Moment
Reference
0.037
Alternate Aft Body Assembly

11° 15'
GOX and Fuel Pressure
Tunnel Centerline
1.233 D
Helium and Electrical
Tunnel Centerline

LH₂ Fill Line Fairing
Ullage Rocket
(2 Places)
Systems Tunnel
Helium Tunnel Assembly
Auxiliary Propulsion
LH₂ Feed Line Fairing (5 Places)
Reaction Control Engine (4 Places)
Module (2 Places)
Ullage Rocket (8 Places)
33°
8° 58'
B
C
GOX and Fuel Pressure Tunnel
0.179 D
A
16° 58'
15° + 0 0.087 D
32
0.013R
0.941
0.518 D
A
Systems Tunnel
B
C
Helium and Electrical Tunnel
Moment Reference
Base Deflector
(8 Places)
0.109
1.572
1.131
1.723
0.766
2.555
4.894
0.037
0.207
0.603
0.660
14.111

11° 15'
GOX and Fuel Pressure
Tunnel Centerline
1.233 D
Base Deflector (8 Places)
Helium and Electrical
Tunnel Centerline

All Dimensions in Inches

c. Saturn V LOR (0.3366-percent Scale Model)
Fig. 1 Continued

10°

0.456

0.185

0.117

0.469

0.109

0.015

30°

0.337R

15°

0.206

1.055

0.013

5° 46´

0.054

0.666R

All Dimensions in Inches

d. Saturn V LOR Fin and Shroud Details (0.3366-percent Scale Model)
Fig. 1 Continued

Section C-C

0.0013R

7° 25′

Systems
Tunnel
Centerline

0.035

0.220

0.041

2° 53′

10°

0.605

0.120

43°

C

C

65° 33′

2° 53′

0.945

30°

0.275

0.096

Fin Details

Ullage Rocket Centerline

30°

45° (Typ)

LH$_2$ Feed Line
Fairing Centerline

1.430 D

1° 36′

Auxiliary Propulsion
Module Centerline

31° 4′

Section A-A

0.192R

1.175 D

1.413 D
(Ref.
Diameter)

45°

Section B-B

Moment Reference

0.745

1.485 D

30°

0.253

Alternate Aft Body Reference

A = 1.569 In.^{2}
A$_b$ = 1.733 in.^{2}
d = 1.413 in.^{2}

1.078 D

Ullage Rocket (3 Places)

Systems Tunnel

Auxiliary Propulsion Module
(2 Places)

A

B

LH$_2$ Feed Line Fairing
(4 Places)

Moment Reference

45° (Typ)

25°

0.847 D

8° 58′

1.430 D

0.116R

+α

0.745

2.592

6.790

11.637

A

A

B

B

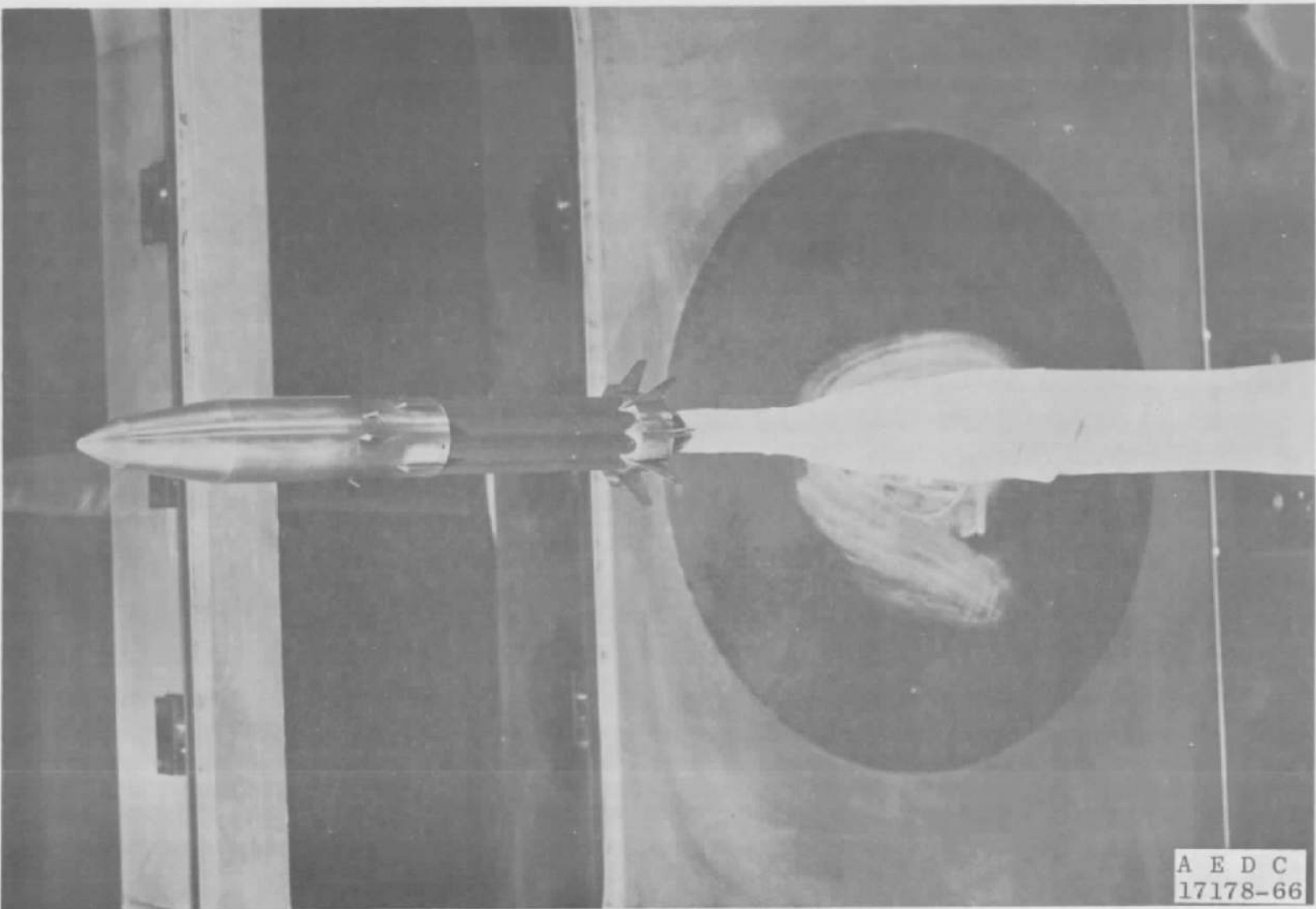1.485 D

1.078 D

0.253

All Dimensions in Inches

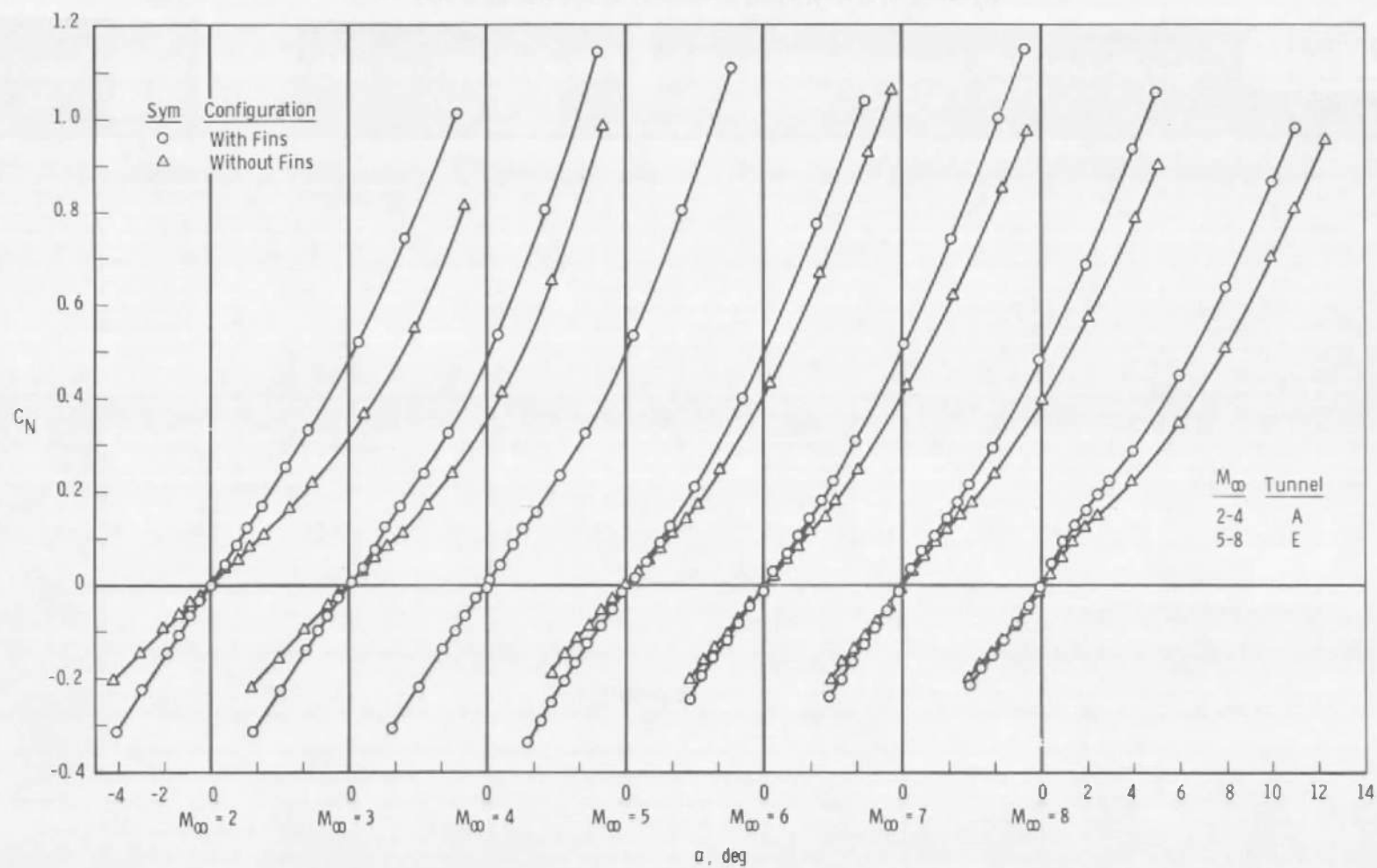e. Saturn 1B/AS-206 Details
Fig. 1 Concluded

AEDC
15847-66

a. Saturn V LOR (0.9-percent Scale Model) in Tunnel A
Fig. 2 Model Installation Photographs

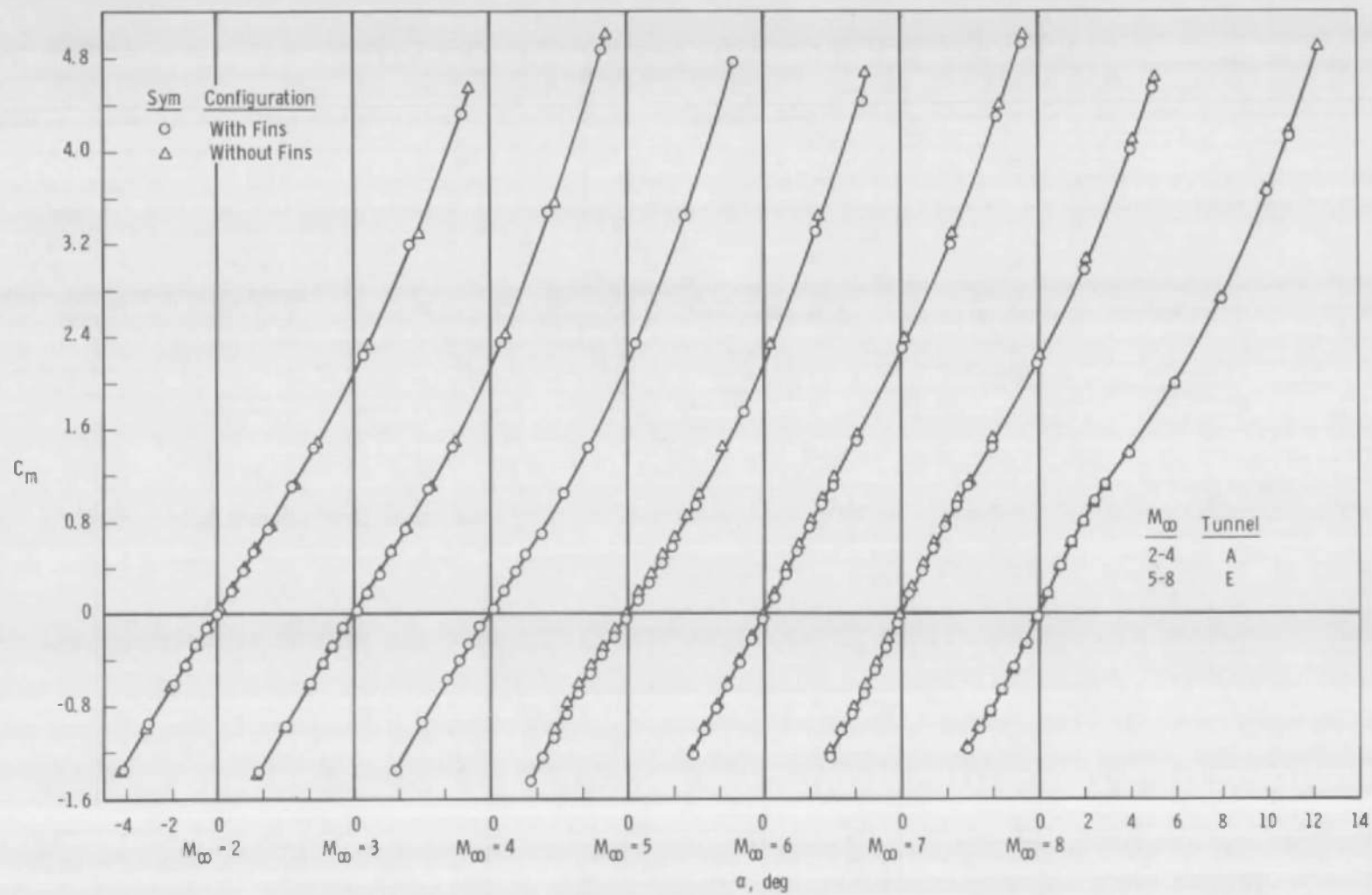b. Saturn V LOR (0.3366-percent Scale Model) in Tunnel E
Fig. 2 Continued

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c. Saturn 1B/AS-206 (0.55-percent Scale Model) in Tunnel A
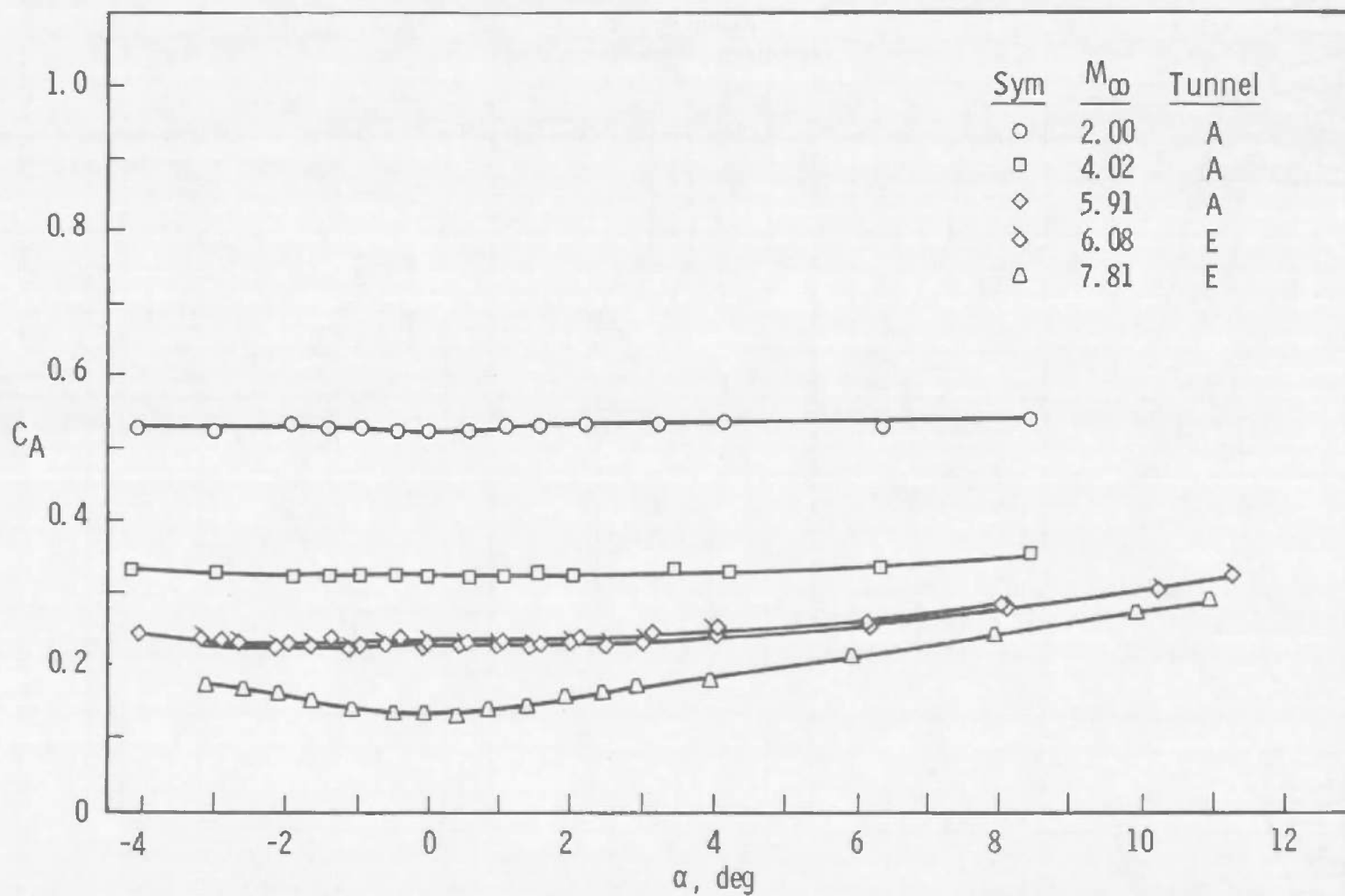Fig. 2 Concluded

a. Normal-Force Coefficient

Fig. 3 Saturn V LOR Static Longitudinal Stability and Axial-Force Characteristics

b. Pitching-Moment Coefficient
Fig. 3 Continued

c. Forebody Axial-Force Coefficient (with Fins)
Fig. 3 Concluded

Fig. 4 Variotians with Mach Number of Static Longitudinal Stability and Axial-Farce Parameters, Saturn V LOR

a. Normal-Force Coefficient

Fig. 5 Saturn 1B/AS-206 Static Longitudinal Stability and Axial-Force Characteristics

b. Pitching-Moment Coefficient
Fig. 5 Continued

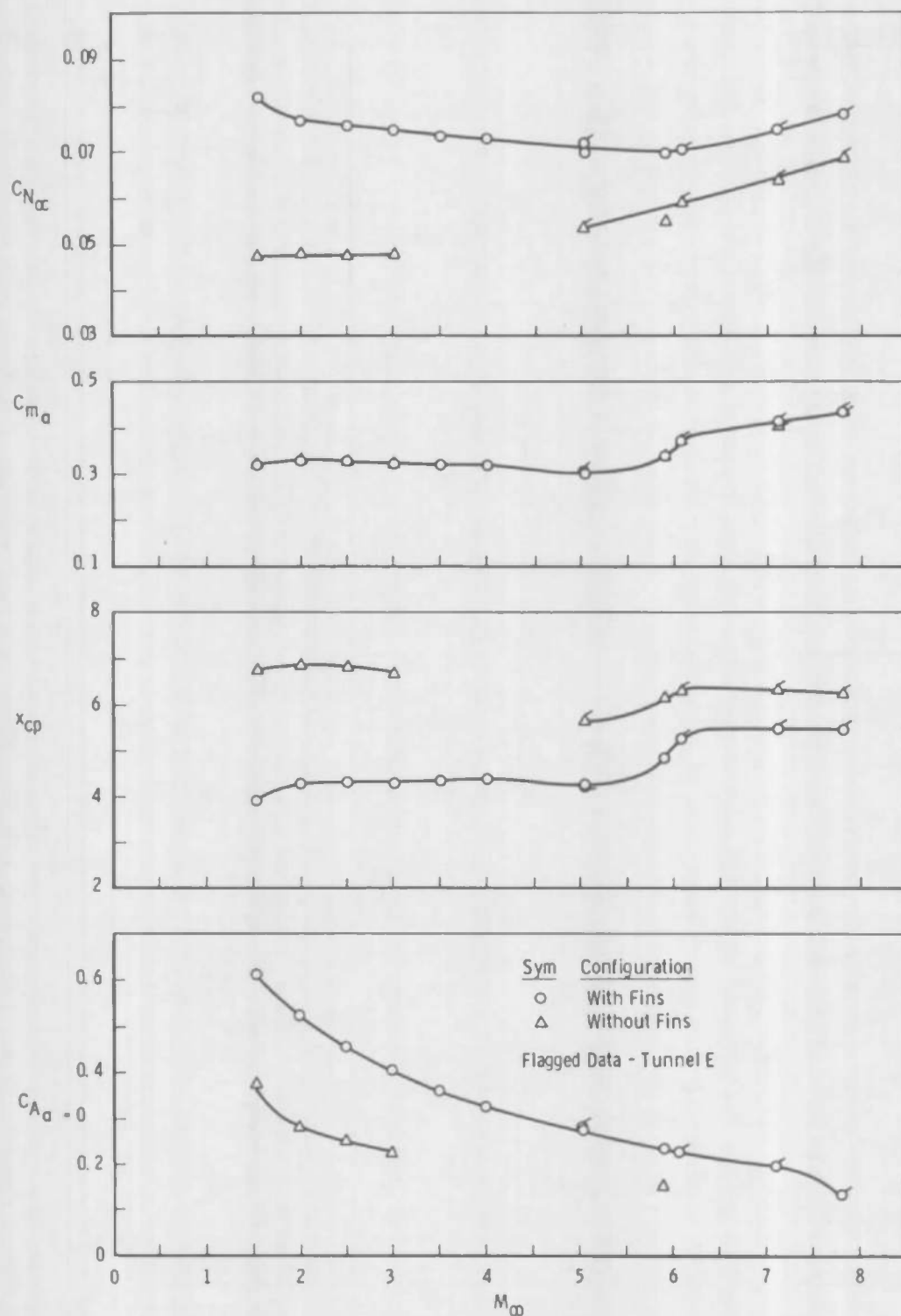c. Forebody Axial-Force Coefficient (with Fins)
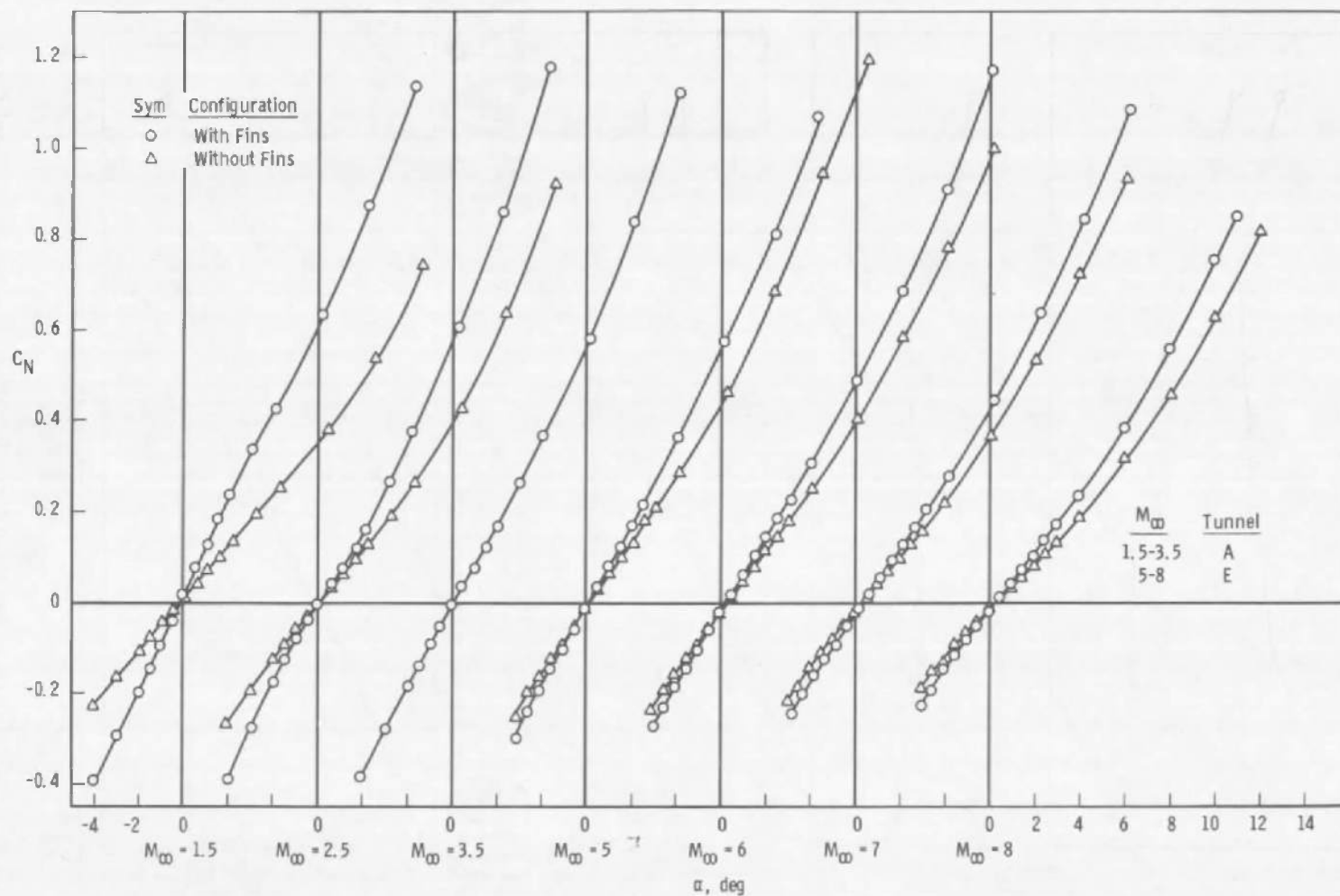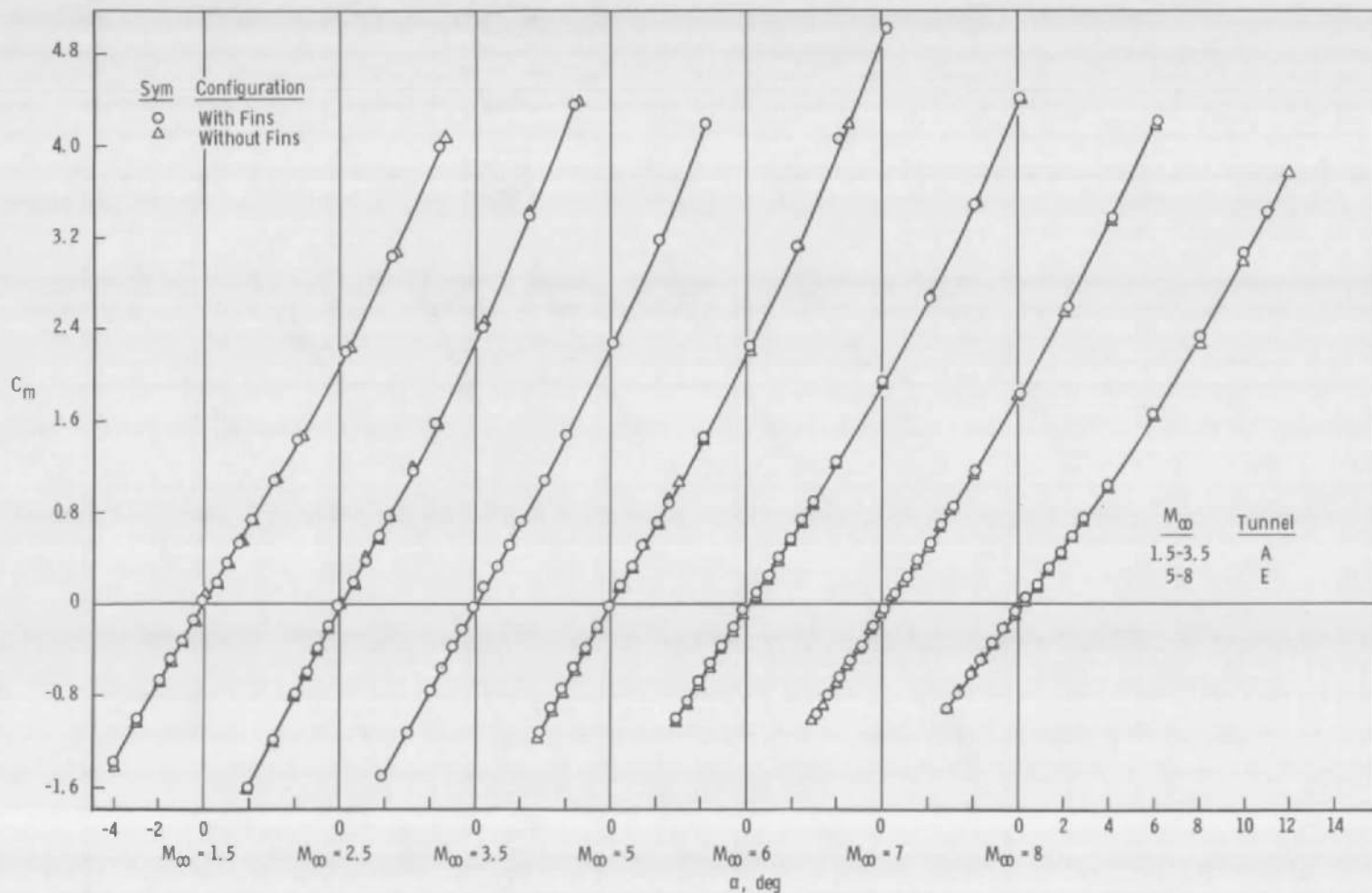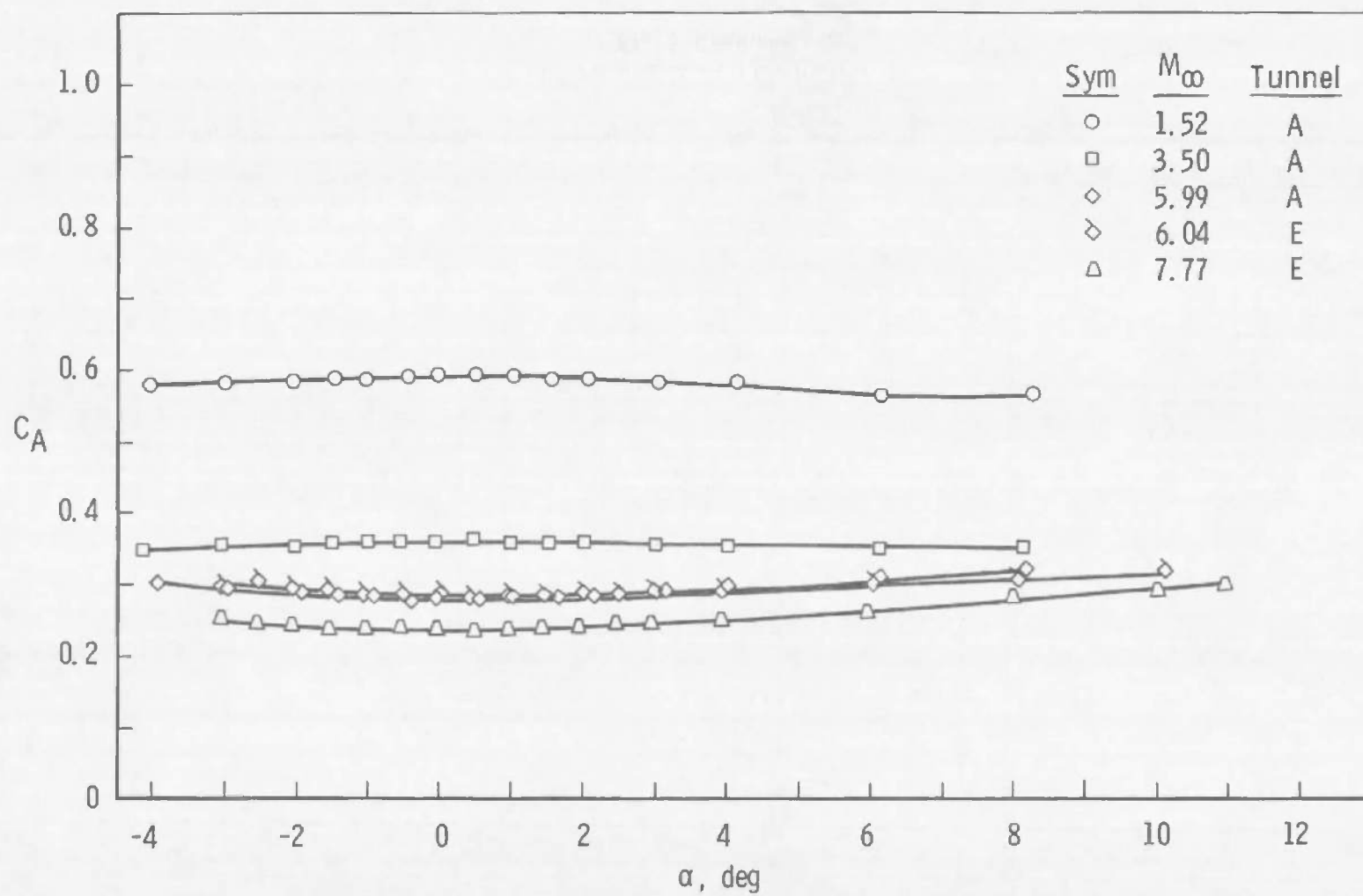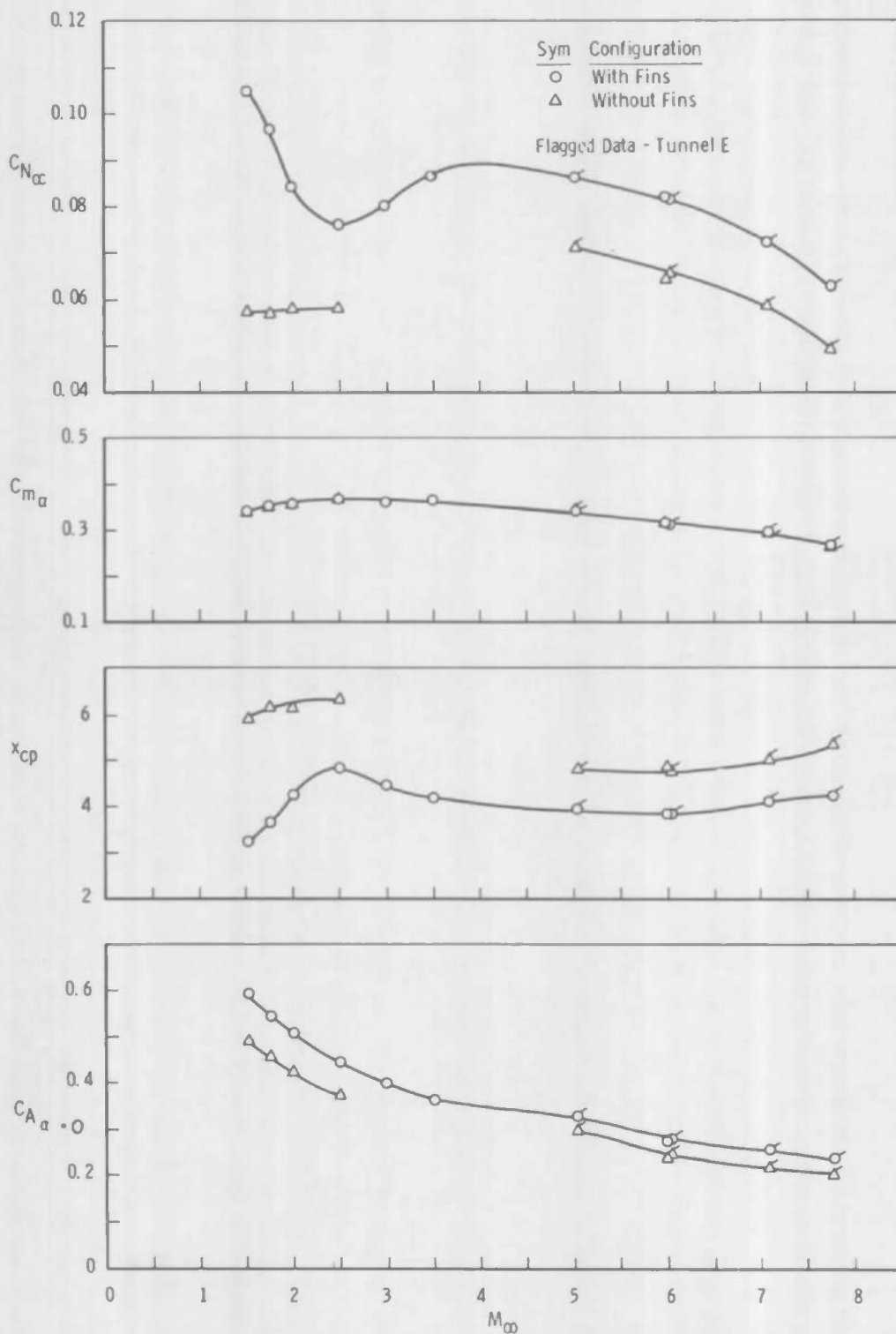Fig. 5 Concluded

Fig. 6 Variations with Mach Number of Static Longitudinal Stability and Axial-Force
Parameters, Saturn 1B/AS-206

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	ROLE	WT	ROLE	WT	ROLE	WT
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1. Project Saturn IV
2. Lunar orbital vehicle
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It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.